operable to decode variable code rate signal and/or variable modulation signal (variable constellation and/or mapping)

display

decoder

satellite receiver

satellite dish

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

satellite

satellite dish

16 QAM/16 APSK TTCM encoder with bandwidth of at least 3 bit/s/Hz (may be implemented using rate 2/4 constituent encoder)

satellite dish

satellite transmitter

encoder

operable to encode variable code rate signal and/or variable modulation signal (variable constellation and/or mapping)

display

decoder

satellite receiver

satellite dish

satellite communication system

Fig. 1

satellite

satellite earth station

tower

local tower dish

local satellite dish

HDTV STB (Set Top Box) receiver

decoder

HDTV display

HDTV transmitter

encoder

coaxial cable

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

operable to decode variable code rate signal and/or variable modulation signal (variable constellation and/or mapping)

16 QAM/16 APSK TTCM encoder with bandwidth of at least 3 bit/s/Hz (may be implemented using rate 2/4 constituent encoder)

operable to encode variable code rate signal and/or variable modulation signal (variable constellation and/or mapping)

HDTV (High Definition Television) communication system

Fig. 2

Fig. 3A

base station receiver

decoder

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

operable to decode variable code rate signal

operable to decode variable modulation signal (constellation and/or mapping)

wireless communication channel

cellular tower

local antenna

uni-directional cellular communication system

mobile transmitter

encoder

16 QAM/16 APSK TTCM encoder with bandwidth of at least 3 bit/s/Hz (may be implemented using rate 2/4 constituent encoder)

operable to encode variable code rate signal

operable to encode variable modulation signal (constellation and/or mapping)

Fig. 3B

base station transmitter

encoder

16 QAM/16 APSK TTCM encoder with bandwidth of at least 3 bit/s/Hz (may be implemented using rate 2/4 constituent encoder)

operable to encode variable code rate signal

operable to encode variable modulation signal (constellation and/or mapping)

wireless communication channel

cellular tower

local antenna

uni-directional cellular communication system

mobile receiver

decoder

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

operable to decode variable code rate signal

operable to decode variable modulation signal (constellation and/or mapping)

bi-directional cellular communication system

Fig. 4

microwave receiver

decoder

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

operable to decode variable code rate signal

operable to decode variable modulation signal (constellation and/or mapping)

microwave tower

wireless communication channel

microwave tower

microwave transmitter

encoder

16 QAM/16 APSK TTCM encoder with bandwidth of at least 3 bit/s/Hz (may be implemented using rate 2/4 constituent encoder)

operable to encode variable code rate signal

operable to encode variable modulation signal (constellation and/or mapping)

uni-directional microwave communication system

Fig. 5

bi-directional microwave communication system

Fig. 6

mobile unit receiver

decoder

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

operable to decode variable code rate signal

operable to decode variable modulation signal (constellation and/or mapping)

local antenna

wireless communication channel

local antenna

mobile unit transmitter

encoder

16 QAM/16 APSK TTCM encoder with bandwidth of at least 3 bit/s/Hz (may be implemented using rate 2/4 constituent encoder)

operable to encode variable code rate signal

operable to encode variable modulation signal (constellation and/or mapping)

uni-directional point-to-point radio communication system

Fig. 7

bi-directional point-to-point radio communication system

Fig. 8

transmitter

encoder

16 QAM/16 APSK TTCM encoder with bandwidth of at least 3 bit/s/Hz (may be implemented using rate 2/4 constituent encoder)

operable to encode variable code rate signal

operable to encode variable modulation signal (constellation and/or mapping)

communication channel

receiver

decoder

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

operable to decode variable code rate signal

operable to decode variable modulation signal (constellation and/or mapping)

uni-directional communication system

Fig. 9

bi-directional communication system

Fig. 10

receiver 1

decoder

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

operable to decode variable code rate signal

operable to decode variable modulation signal (constellation and/or mapping)

receiver n

decoder

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

operable to decode variable code rate signal

operable to decode variable modulation signal (constellation and/or mapping)

• • •

distribution point

communication channel

transmitter

encoder

16 QAM/16 APSK TTCM encoder with bandwidth of at least 3 bit/s/Hz (may be implemented using rate 2/4 constituent encoder)

operable to encode variable code rate signal

operable to encode variable modulation signal (constellation and/or mapping)

one to many communication system

Fig. 11

DWDM (Dense Wavelength Division Multiplexing) line card

fiber-optic interfacing

line side

transmitter
e/o converter

receiver
o/e converter

DWDM transport processor

encoder

decoder

TTCM decoder operable to decode 16 QAM/16 APSK TTCM coded signals with bandwidth of at least 3 bit/s/Hz

operable to decode variable code rate signal and/or variable modulation signal (variable constellation and/or mapping)

10G serial module

fiber-optic interfacing

client side

alternatively, non-fiber-optic interfacing

16 QAM/16 APSK TTCM encoder with bandwidth of at least 3 bit/s/Hz (may be implemented using rate 2/4 constituent encoder)

operable to encode variable code rate signal and/or variable modulation signal (variable constellation and/or mapping)

fiber-optic communication system

Fig. 12

Fig. 13

satellite receiver STB (Set Top Box) system
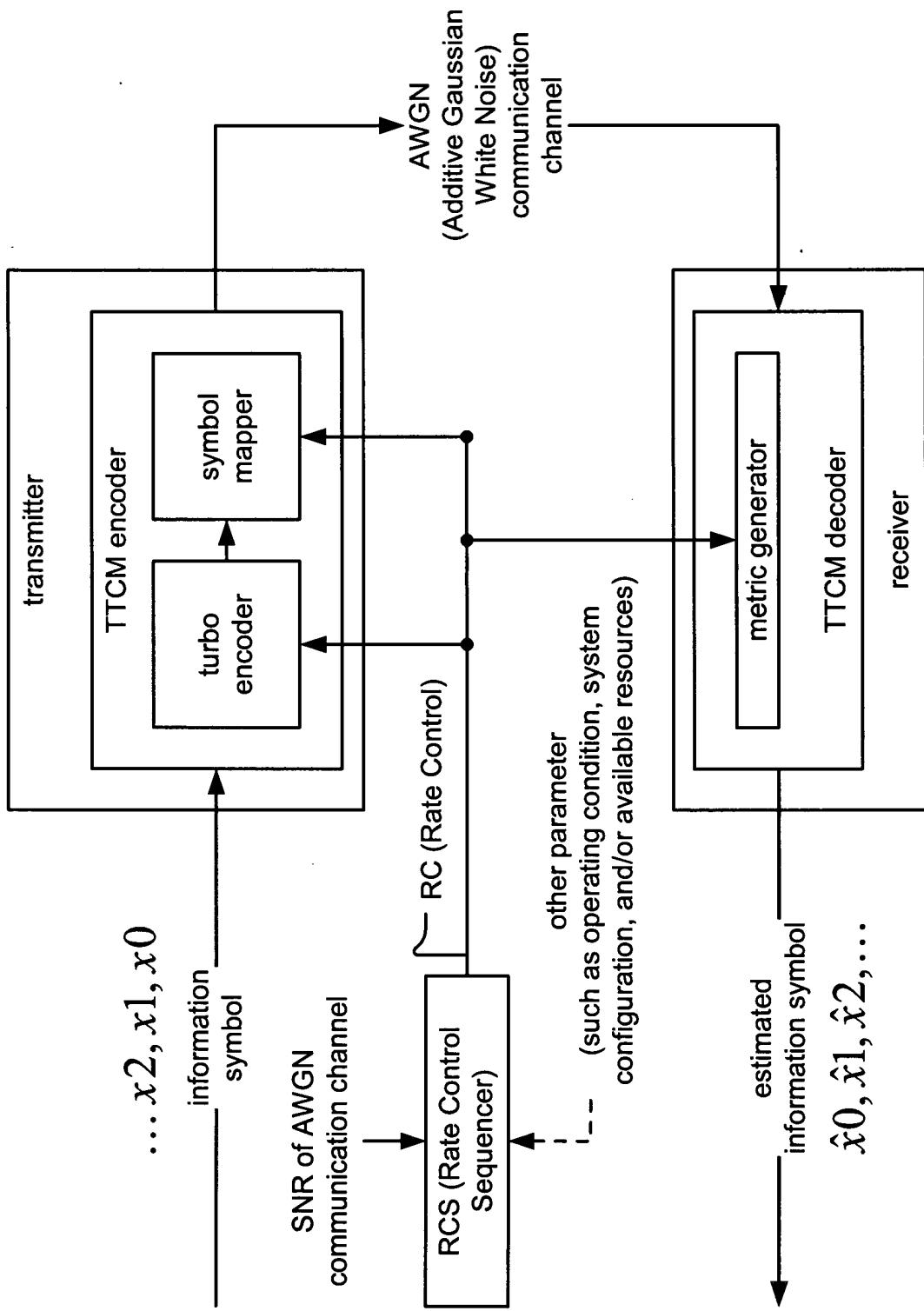
TTCM (Turbo Trellis Coded Modulation) communication system

Fig. 14
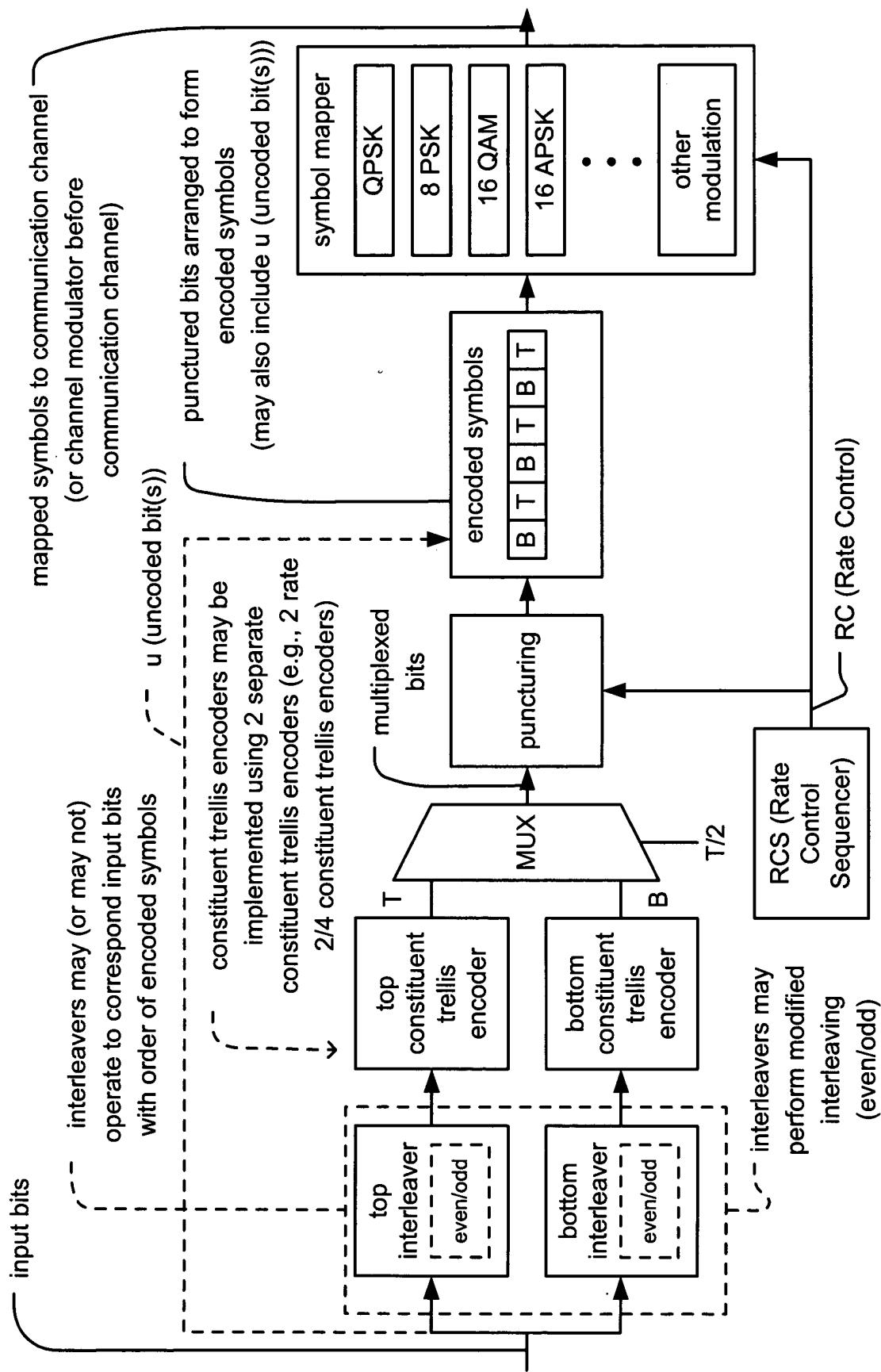
dual interleaver embodiment of TTCM (Turbo Trellis Coded Modulation) encoder

Fig. 15

b output bits
(input bits explicit in output)

u
(uncoded bit(s))

a input bits

may be top CTE
(constituent trellis encoder)
or bottom CTE

c_x

redundancy
bits
(or parity bits)

$c_{(x-1)}$

$\cdots$ c_0

$i_{(a-1)}$ $\cdots$ i_1 i_0

input bits
(within output)

rate a/b systematic encoder

i_0
i_1
$\cdots$
$i_{(a-1)}$
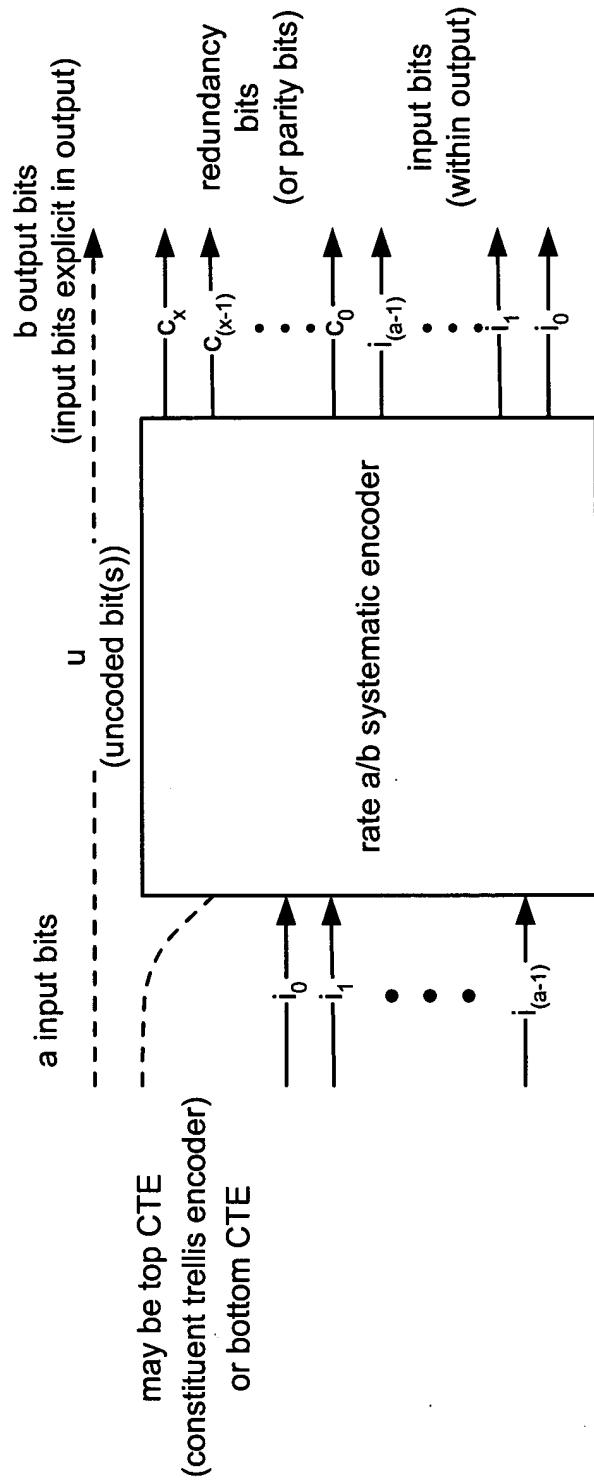
systematic constituent encoder

Fig. 16A

u_k (uncoded bit)

$i_{k,m}$
$i_{k,l}$
$r_{k,l}$
$r_{k,m}$

rate 2/4 encoder

u_k

$i_{k,m}$
$i_{k,l}$
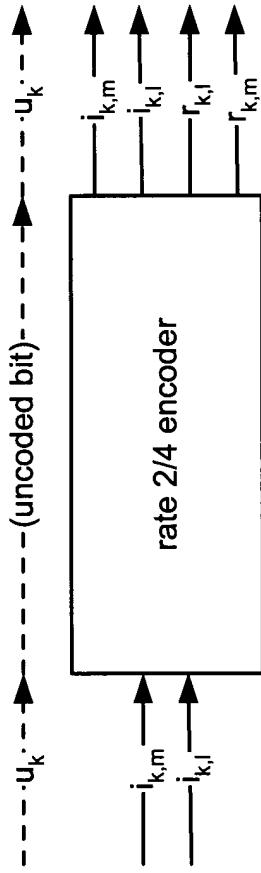
rate 2/4 constituent encoder

Fig. 16B
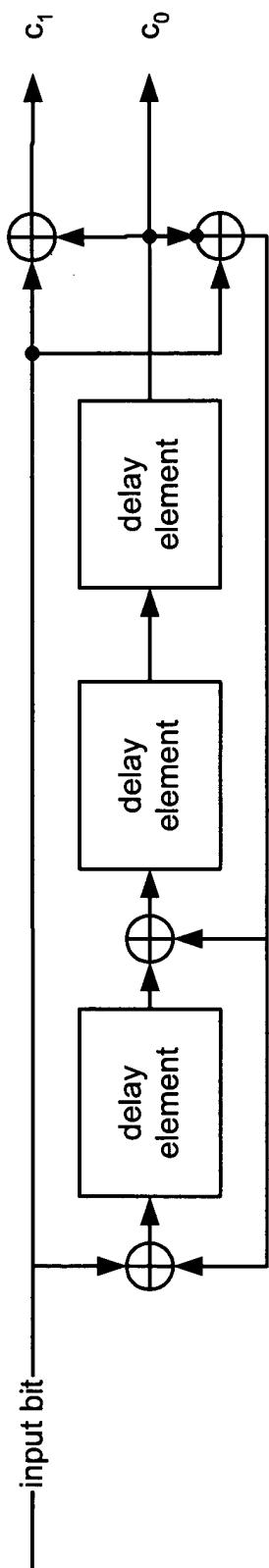
rate 1/2 recursive convolutional encoder with non-systematic output

Fig. 17A
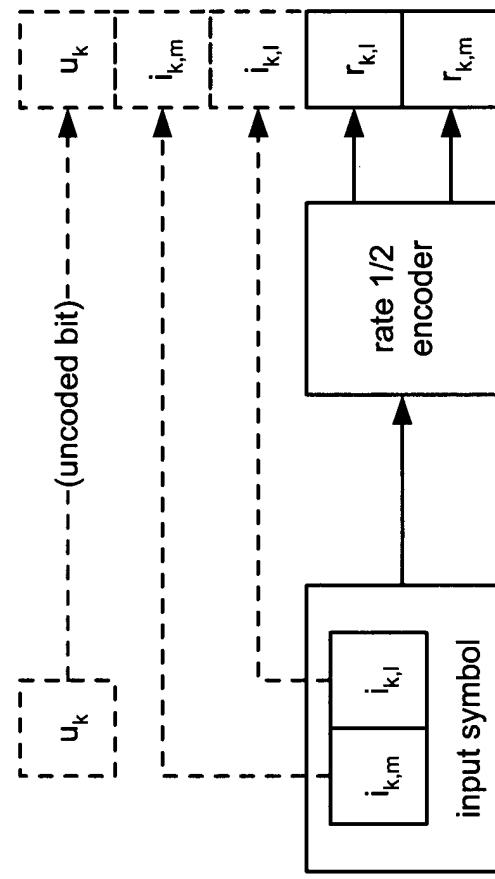
rate 2/4 prototype encoder

Fig. 17B
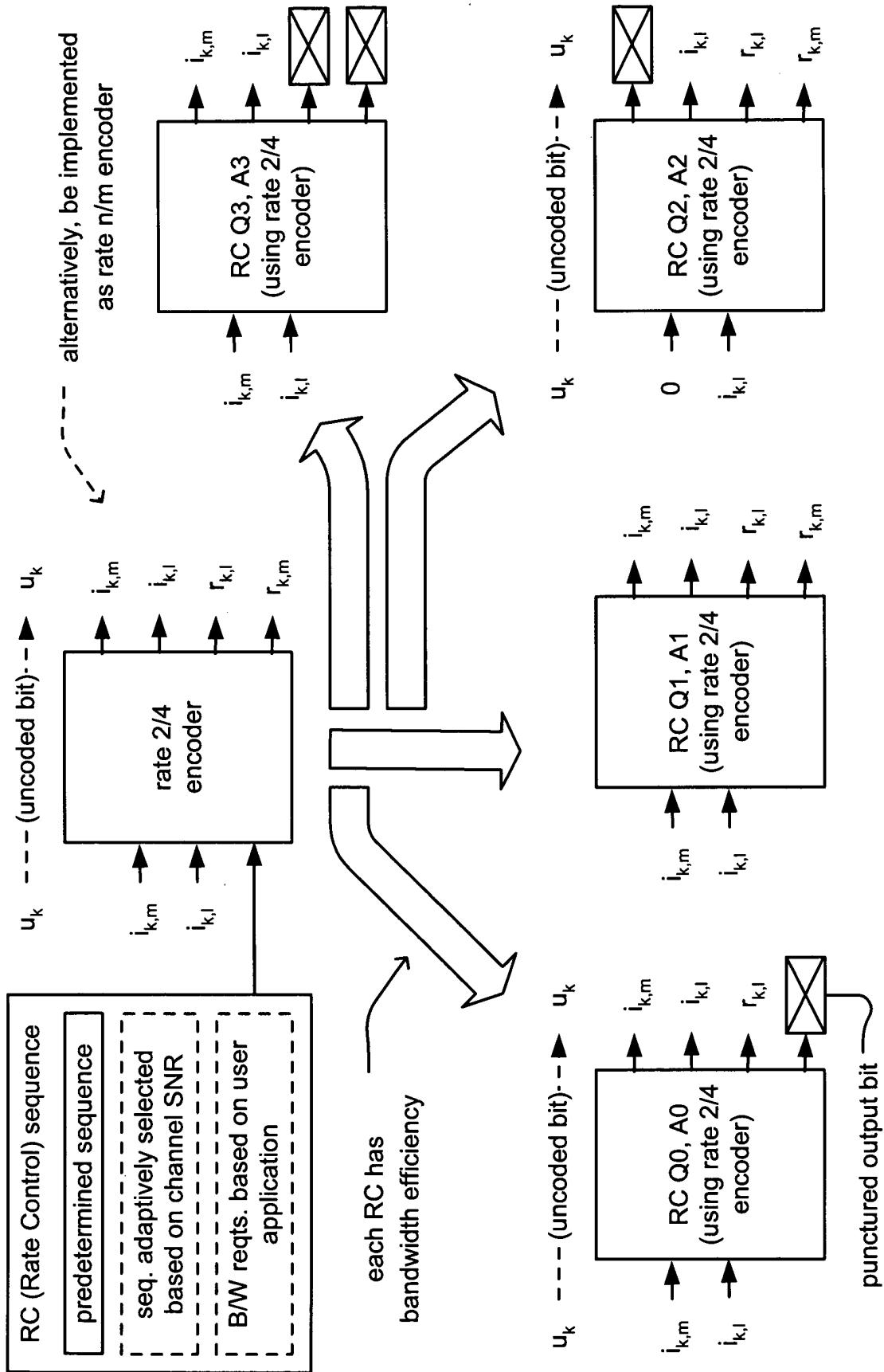
rate 2/4 prototype encoder supporting multiple encoders

Fig. 18

Fig. 19

RC (Rate Control) governed symbol mapping to various constellations

Fig. 20

RC (Rate Control) governed symbol mapping to various constellations

RC (Rate Control) sequence

u_0 — — (1st uncoded bit)

u_1 — — (2nd uncoded bit)

$i_{k,m}$

$i_{k,l}$

RC Q4, A4 (using rate 2/4 encoder)
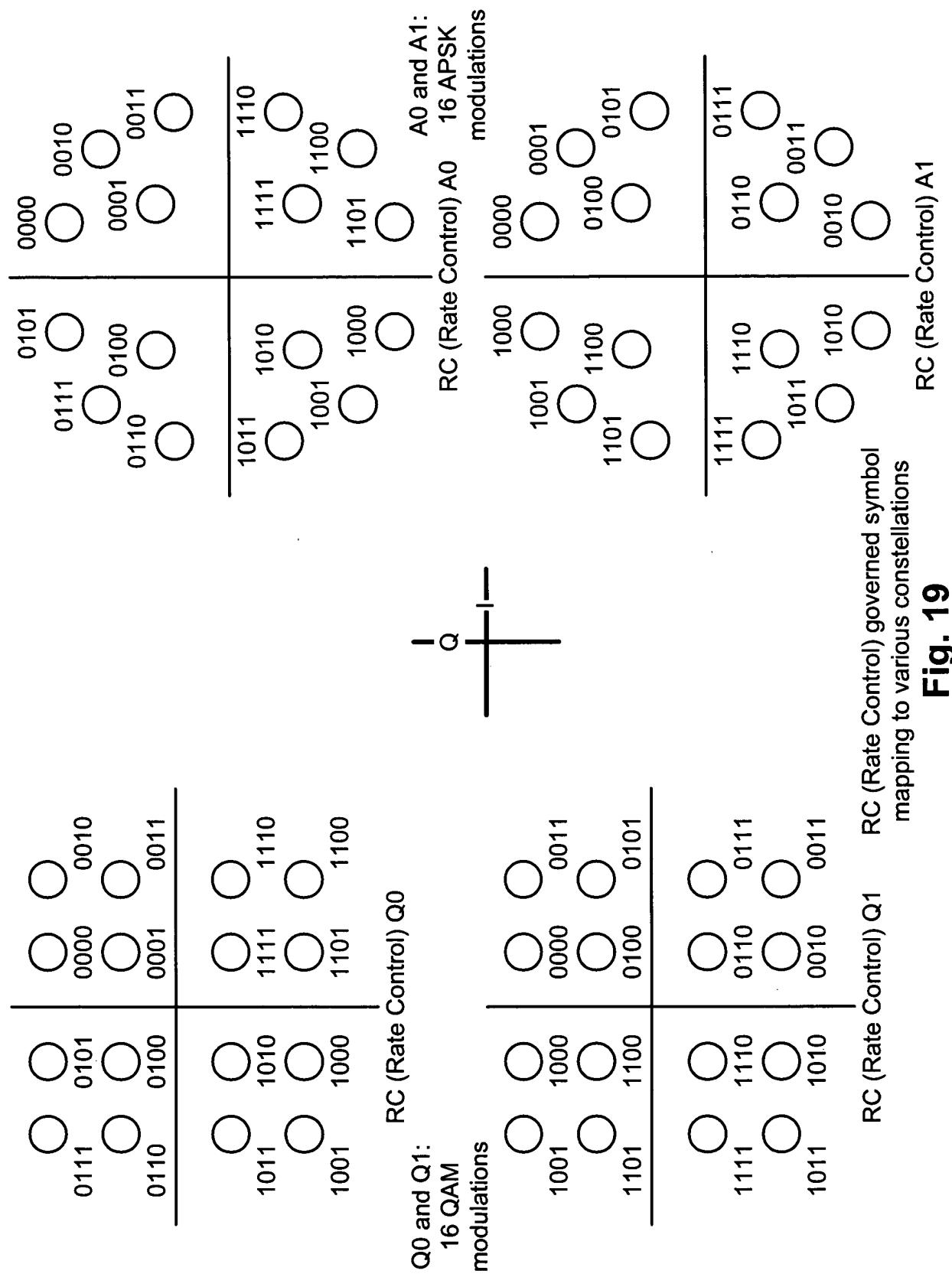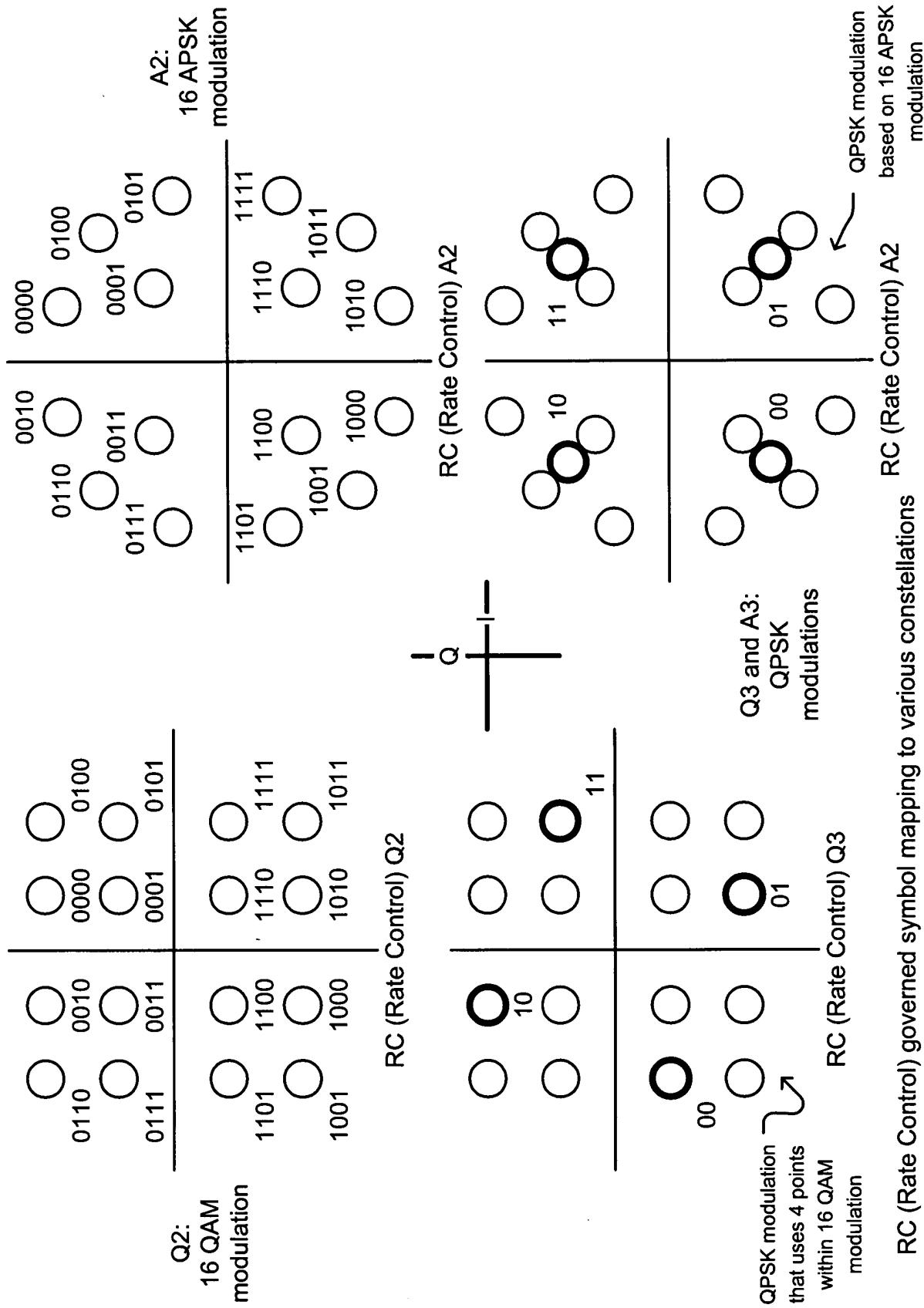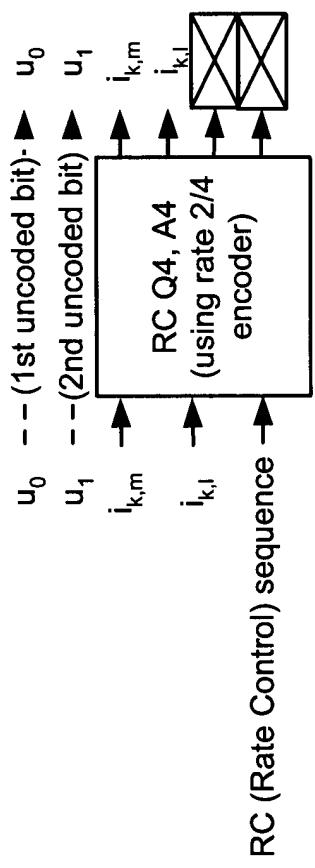
rate 2/4 prototype encoder supporting RCs Q4, A4 (each having 2 uncoded bits)

Fig. 21A

Q4: 16 QAM modulation

RC (Rate Control) Q4

A4: 16 APSK modulation
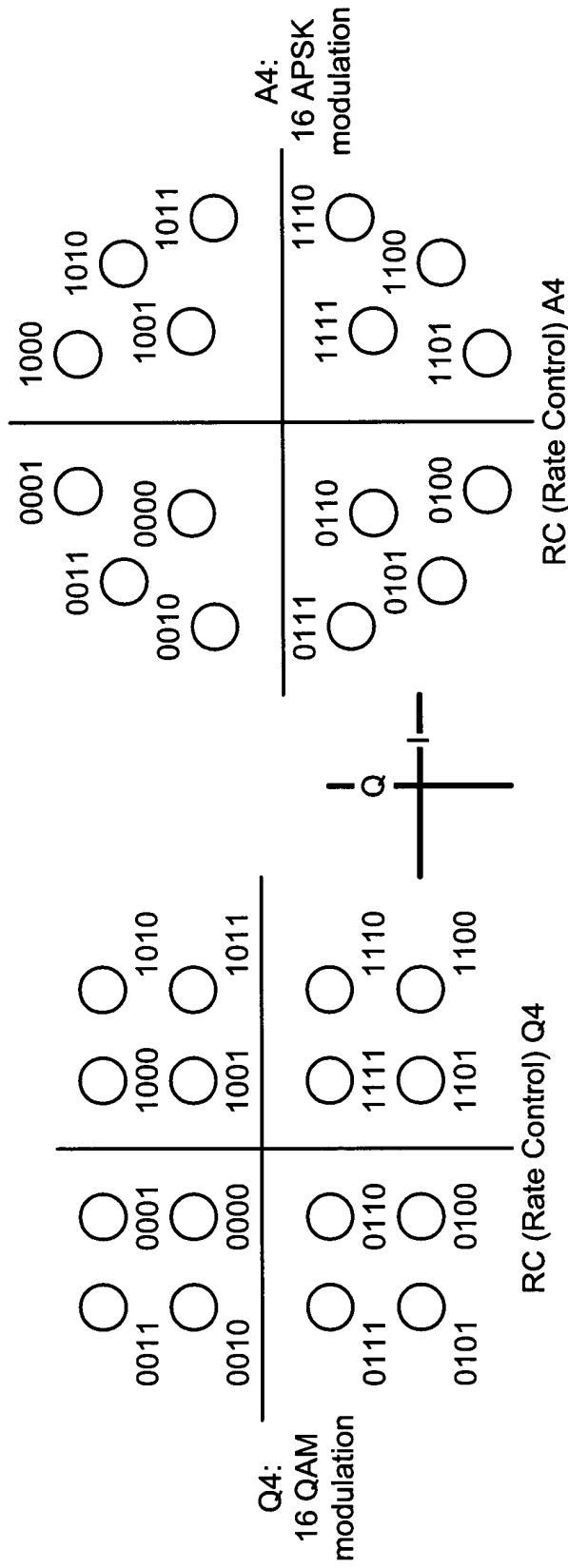
RC (Rate Control) A4

RC (Rate Control) governed symbol mapping to various constellations

Fig. 21B

bandwidth	a period of a s qu nce for 16 QAM	a period of a sequenc for 16 APSK
3.33 bit/s/Hz	Q0 Q0 Q4	A0 A0 A4
3.5 bit/s/Hz	Q0 Q0 Q4 Q4	A0 A0 A4 A4

periodic RC (Rate Control) sequences of TTCM supporting bandwidths of at least 3 bit/s/Hz

Fig. 22A
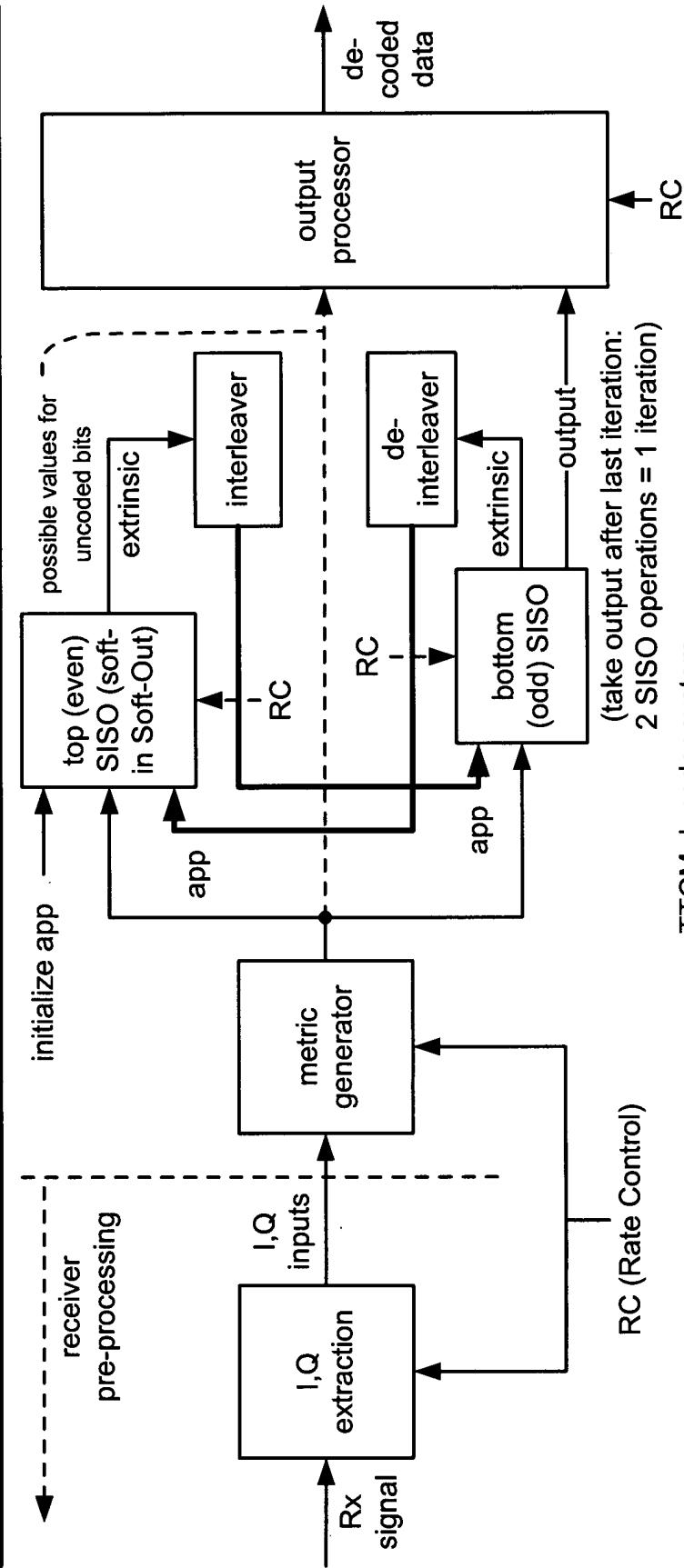
TTCM decoder system

Fig. 22B
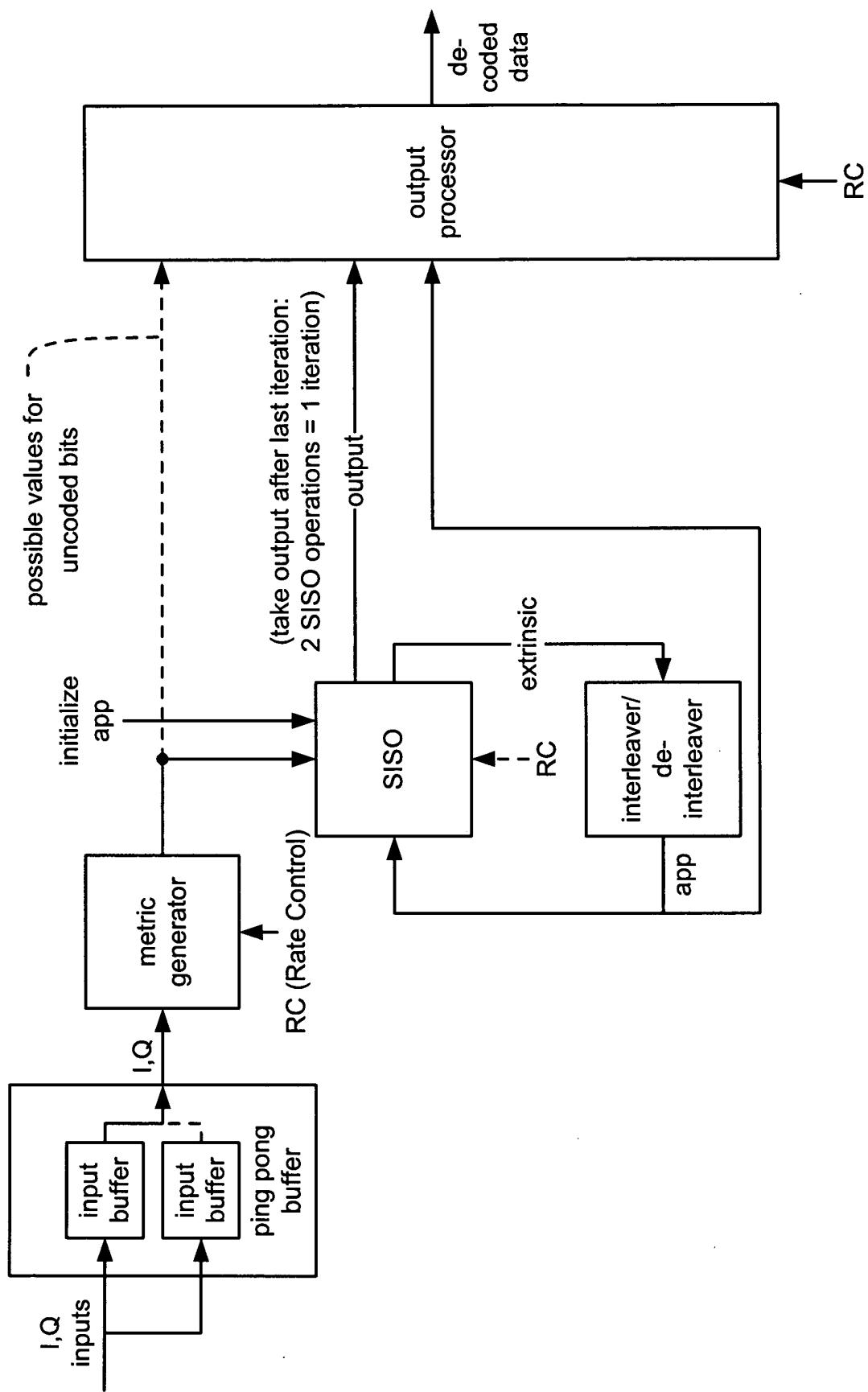
alternative TTCM decoder system that recycles single SISO (receiving I,Q inputs)

Fig. 23
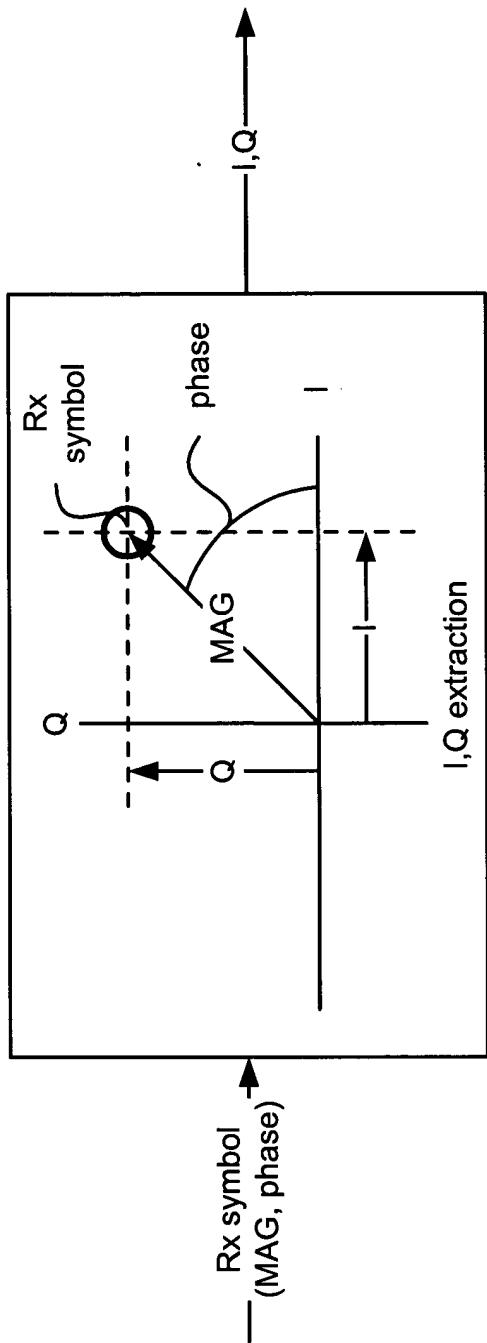
I,Q (In-phase, Quadrature) extraction

Fig. 24A

Rx symbol
(MAG, phase)

Rx symbol

phase

MAG

Q

I

I,Q

map Rx I,Q to appropriate modulation (constellation and its mapping)

constellation #1

constellation #2

constellation #x

received symbols correspond to
one of the constellations

mapping #1

mapping #2

mapping #y

each constellation may have
one or more mappings

mapped
symbol
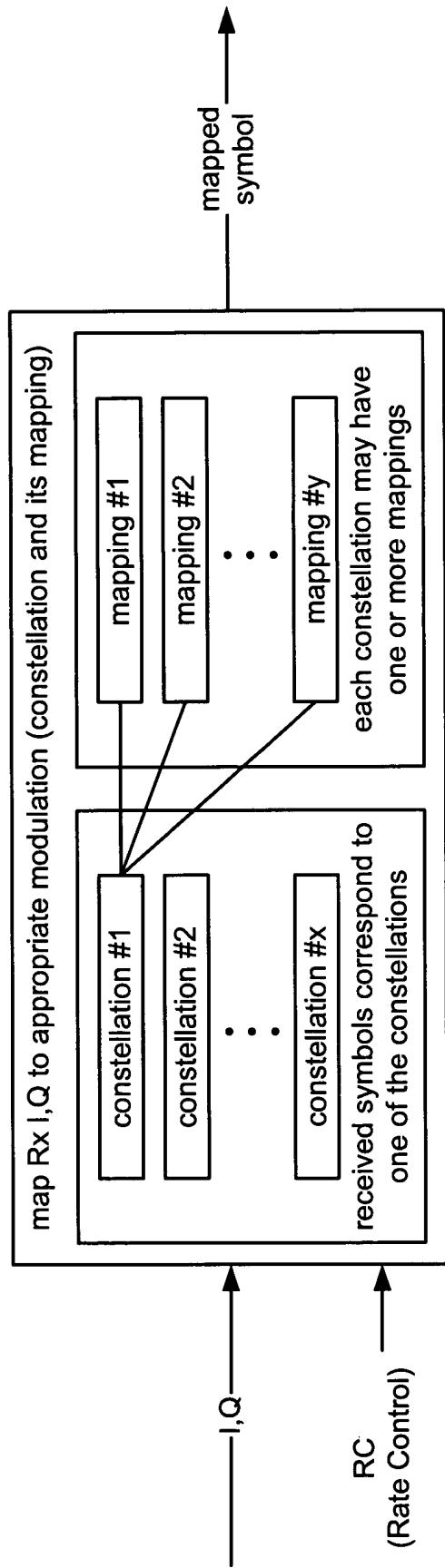
Rx I,Q mapping based on RC

Fig. 24B

I,Q

RC
(Rate Control)

Rx symbol

M(3)

3=11

2=10

M(1)

1=01

M(2)

M(0)

0=00

RC Q3

Q
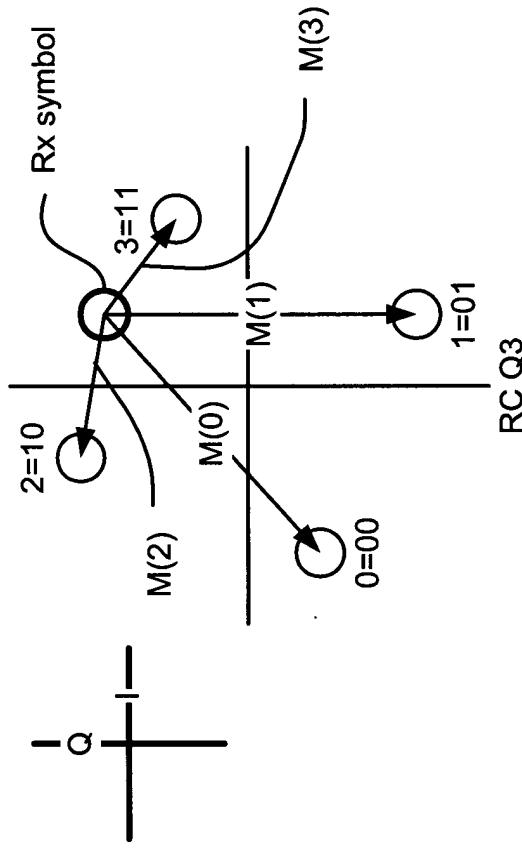
metric calculation performed by metric generator (shown for RC Q3 embodiment)

Fig. 25A

trellis
metrics (M_t) for use in SISO(s)

based on RC,
transform Rx, indexed
metrics (M_r) to trellis
metrics (M_t)

RC (Rate Control)

Rx indexed
metrics
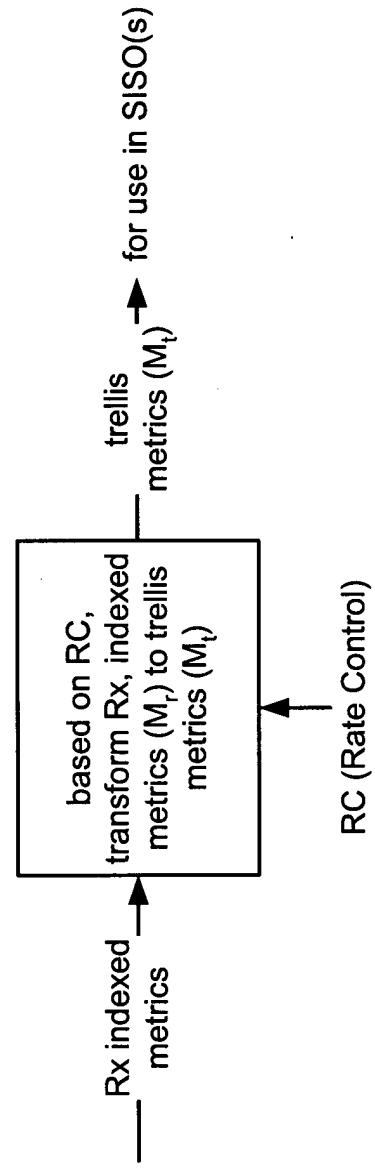
metric mapping functionality

Fig. 25B

frame of Rx symbols

| S1 (Symbol 1) | S2 | S3 | S4 | ... | Sn |

alpha — trellis stage — beta (for each of S1, S2, S3, S4, Sn)

to interleaver/
de-interleaver
and back to
other SISO as
app

extrinsic

extrinsic calculation (using trellis, through all stages)

alpha calculation (using trellis, forward through each stage)

beta calculation (using trellis, backward through each stage)

SISO

Rx metrics mapped to trellis metrics

Rx metrics (from metric generator)

SISO calculations and operations

Fig. 26

both SISOs may be
implemented using same h/w

final output of decoding

Fig. 27A

uncoded bit estimation

$uncoded(b_1, b_0) = (a_1, a_0)$

symbol metrics

metric calculation of 4 possible uncoded bit
combinations a_1, a_0 using min* processing of
coded bits b_1, b_0

metric(00)   metric(10)

metric(01)   metric(11)

Rx
signal
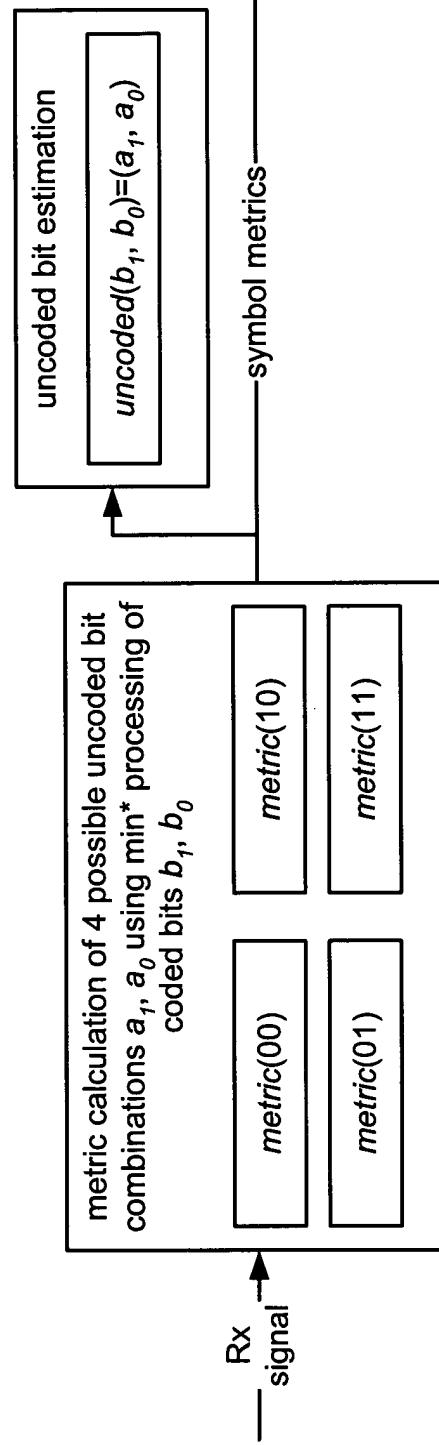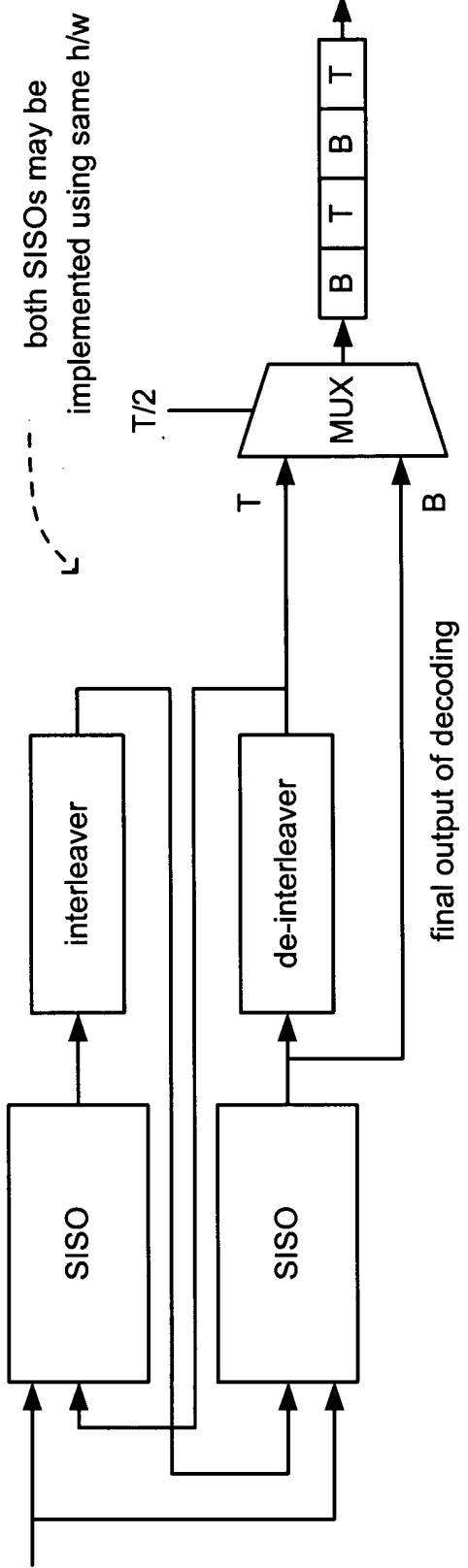
metric generator computation to accommodate RCs Q4 and A4

Fig. 27B
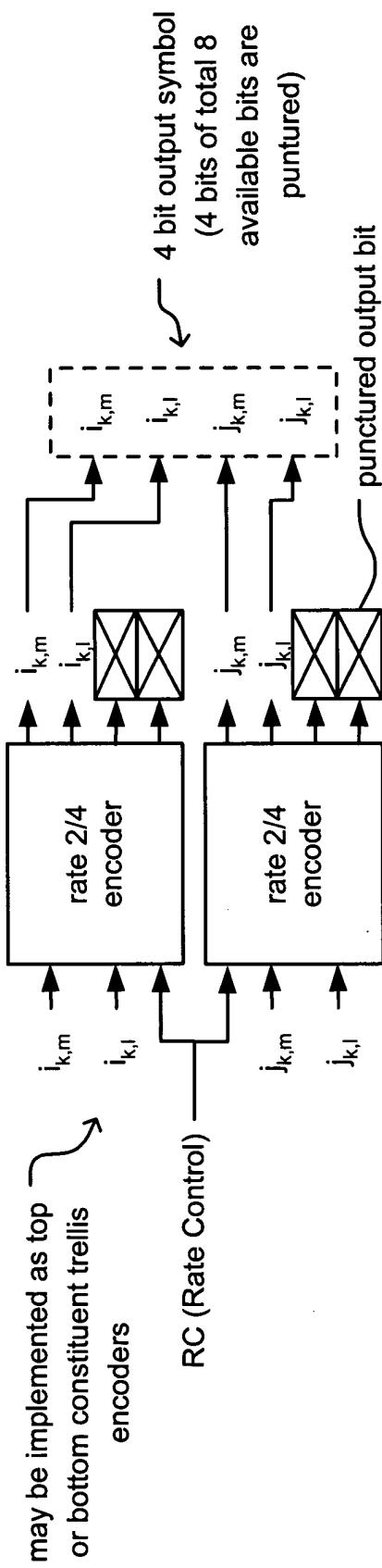
dual rate 2/4 prototype encoders supporting RCs (Q5 Q5) or (A5 A5)

Fig. 28A
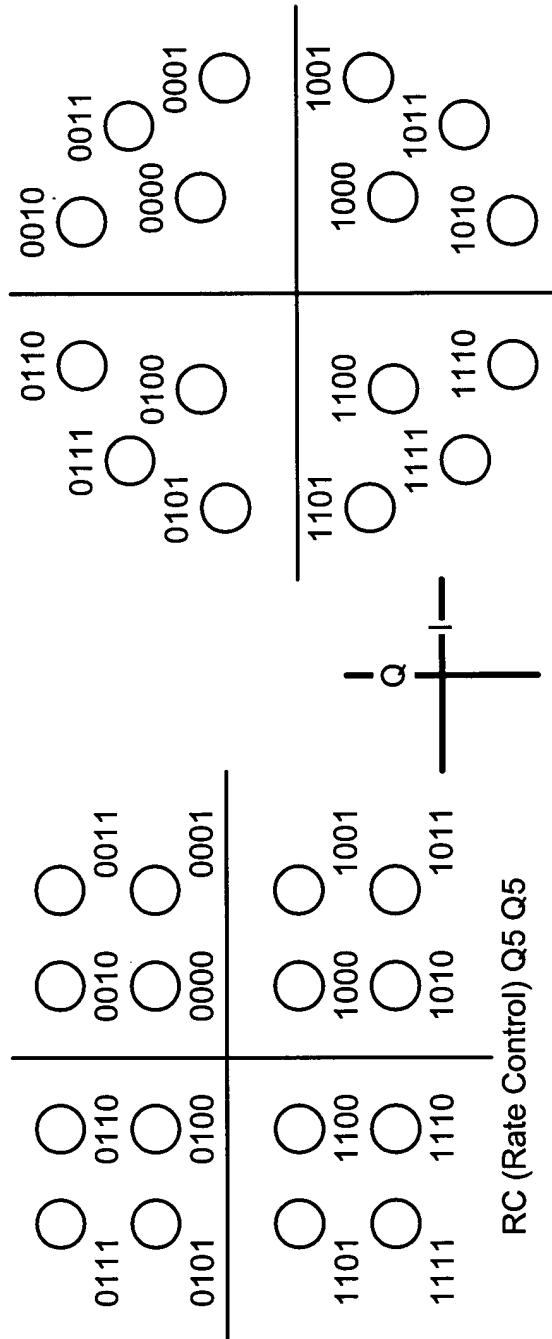
RC (Rate Control) governed symbol mapping to various constellations

Fig. 28B

| bandwidth	a period of a sequence for 16 QAM	a period of a sequence for 16 APSK
3.33 bit/s/Hz	Q0 Q0 (Q5 Q5)	A0 A0 (A5 A5)
3.5 bit/s/Hz	Q0 Q0 (Q5 Q5) (Q5 Q5)	A0 A0 (A5 A5) (A5 A5)

periodic RC (Rate Control) sequences supporting TTCM supporting bandwidth of at least 3 bit/s/Hz

Fig. 29A

2 metrics required (top and bottom)

metric calculation of 4 possible uncoded bit combinations a_1, a_0 using min* processing of coded bits b_1, b_0 for "top" decoder

$metric_T(00)$ $metric_T(10)$

$metric_T(01)$ $metric_T(11)$

metric calculation of 4 possible uncoded bit combinations a_1, a_0 using min* processing of coded bits b_1, b_0 for "bottom" decoder

$metric_B(00)$ $metric_B(10)$

$metric_B(01)$ $metric_B(11)$

Rx signal

symbol metrics →
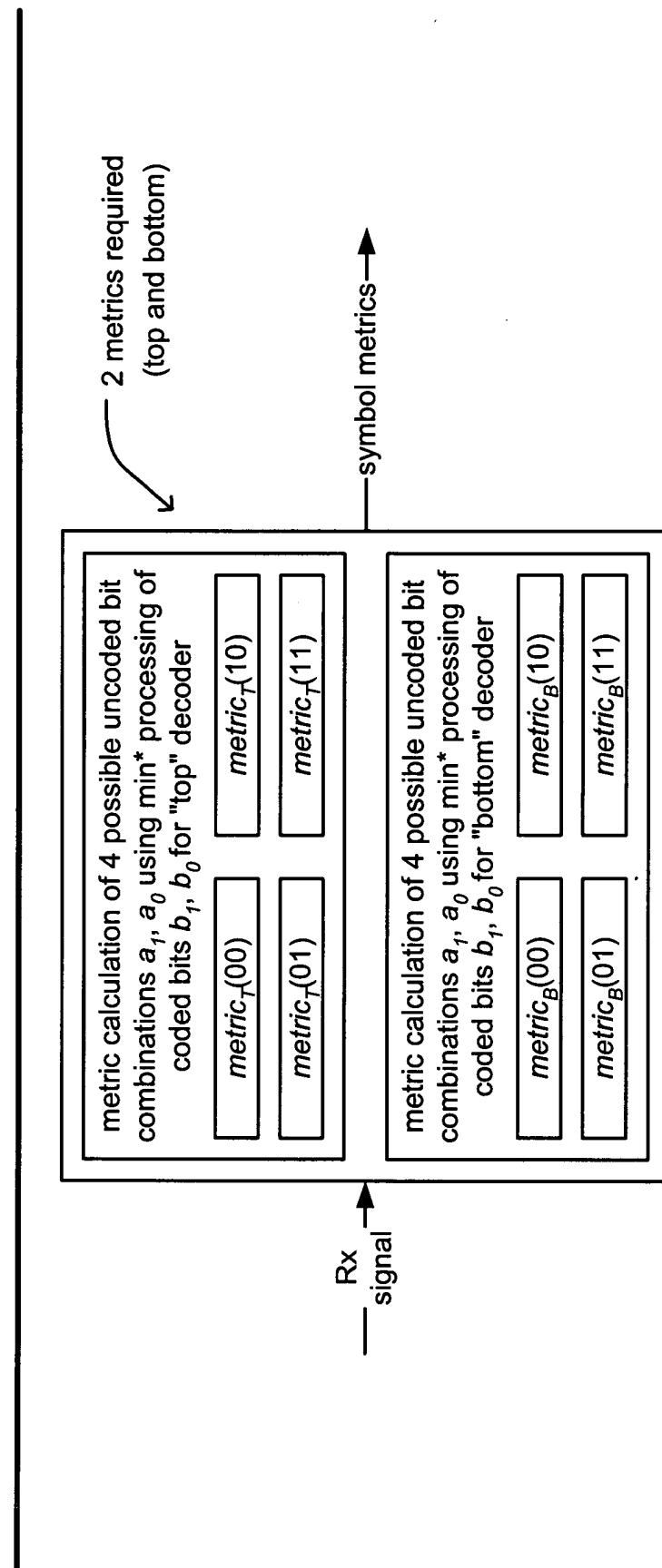
metric generator computation to accommodate RCs (Q5 Q5) and (A5 A5)

Fig. 29B
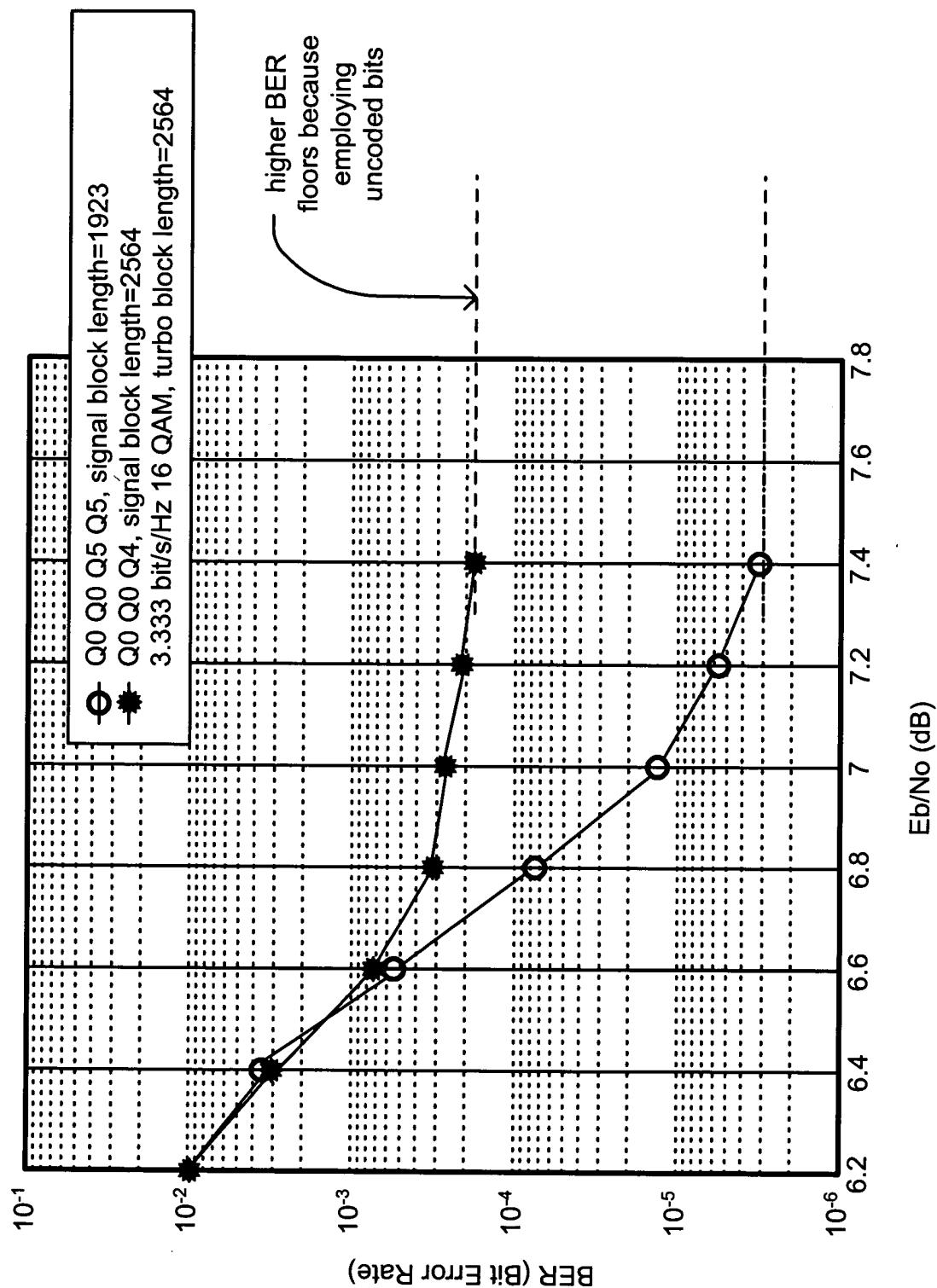
performance of 3.33 bit/s/Hz 16 QAM TTCM (shown with 4 decoding iterations)

Fig. 30
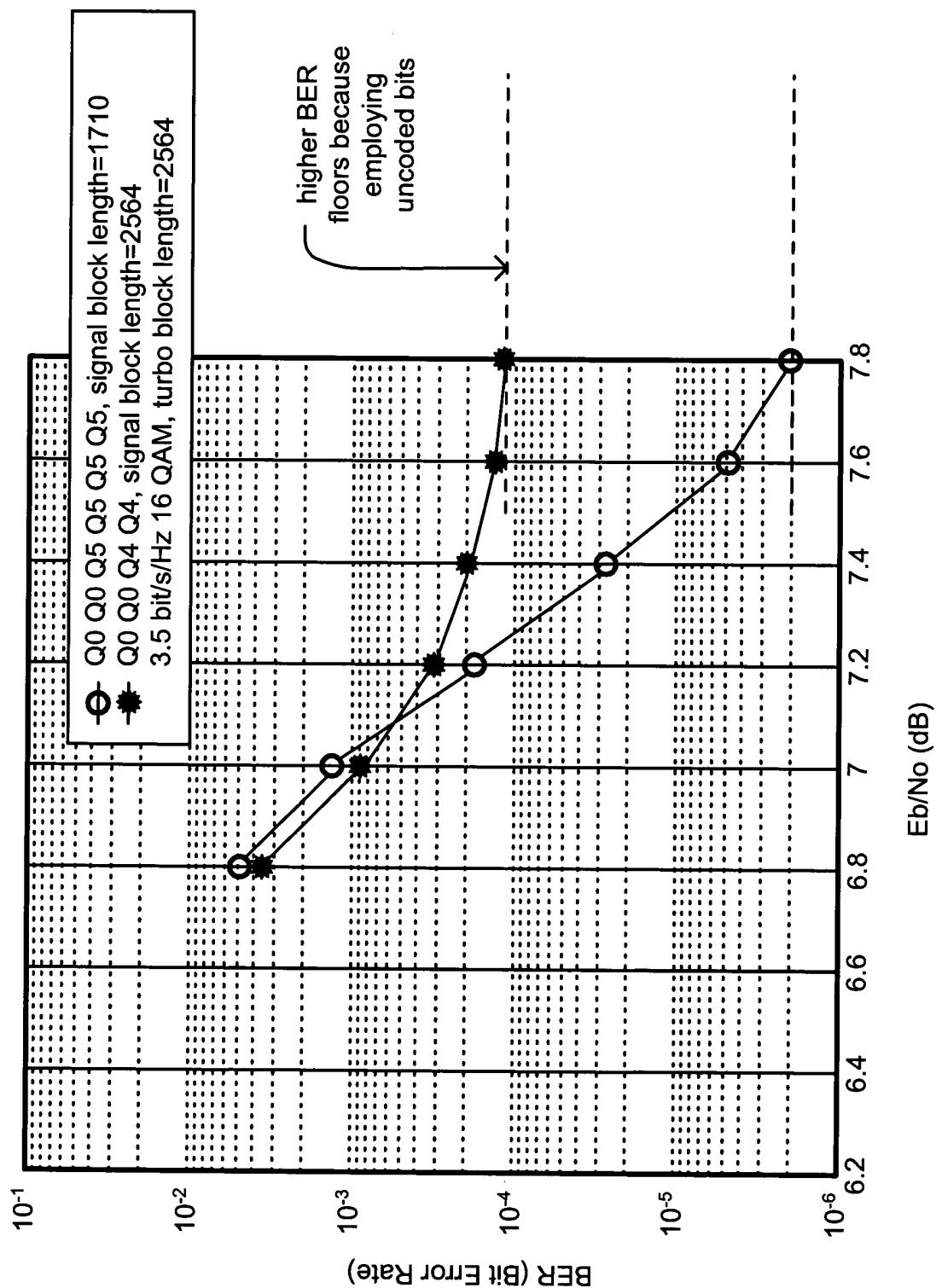
performance of 3.5 bit/s/Hz 16 QAM TTCM (shown with 4 decoding iterations)

Fig. 31

RC sequences include combined 16 QAM and QPSK (Q3) modulations →

RC sequences include combined 16 APSK and QPSK (A3) modulations →

| bandwidth	a period of a sequence for 16 QAM (period 9)	a period of a sequence for 16 APSK (period 9)
3.0 bit/s/Hz	Q4 Q0 Q0 Q0 Q0 Q0 Q0 Q0 Q3, or (Q5 Q5) Q0 Q0 Q0 Q0 Q0 Q0 Q3	A4 A0 A0 A0 A0 A0 A0 A0 A3, or (A5 A5) A0 A0 A0 A0 A0 A0 A3
3.11 bit/s/Hz	Q4 Q0 Q0 Q0 Q4 Q0 Q0 Q0 Q0 Q3, or (Q5 Q5) Q0 Q0 Q0 (Q5 Q5) Q0 Q0 Q0 Q0 Q3	A4 A0 A0 A0 A4 A0 A0 A0 A0 A3, or (A5 A5) A0 A0 A0 (A5 A5) A0 A0 A0 A3
3.33 bit/s/Hz	Q4 Q4 Q0 Q0 Q4 Q4 Q0 Q0 Q0 Q3, or (Q5 Q5) (Q5 Q5) Q0 Q0 (Q5 Q5) (Q5 Q5) Q0 Q0 Q3	A4 A4 A0 A0 A4 A4 A0 A0 A0 A3, or (A5 A5) (A5 A5) A0 A0 (A5 A5) (A5 A5) A0 A0 A3

Fig. 32

combined modulation periodic RC sequences supporting TTCM supporting bandwidth of at least 3 bit/s/Hz
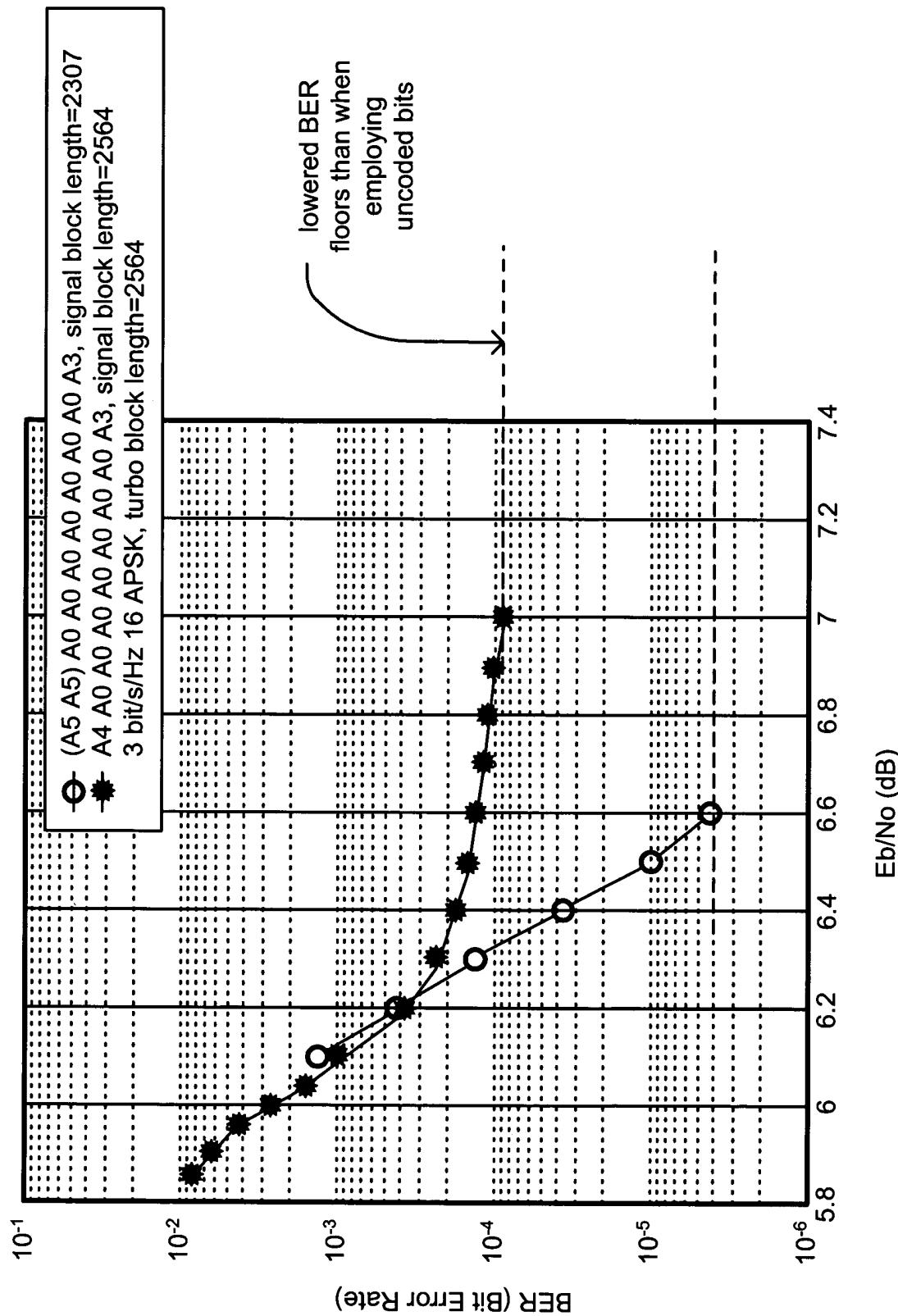
performance of 3.0 bit/s/Hz 16 APSK TTCM (shown with 4 decoding iterations)

Fig. 33
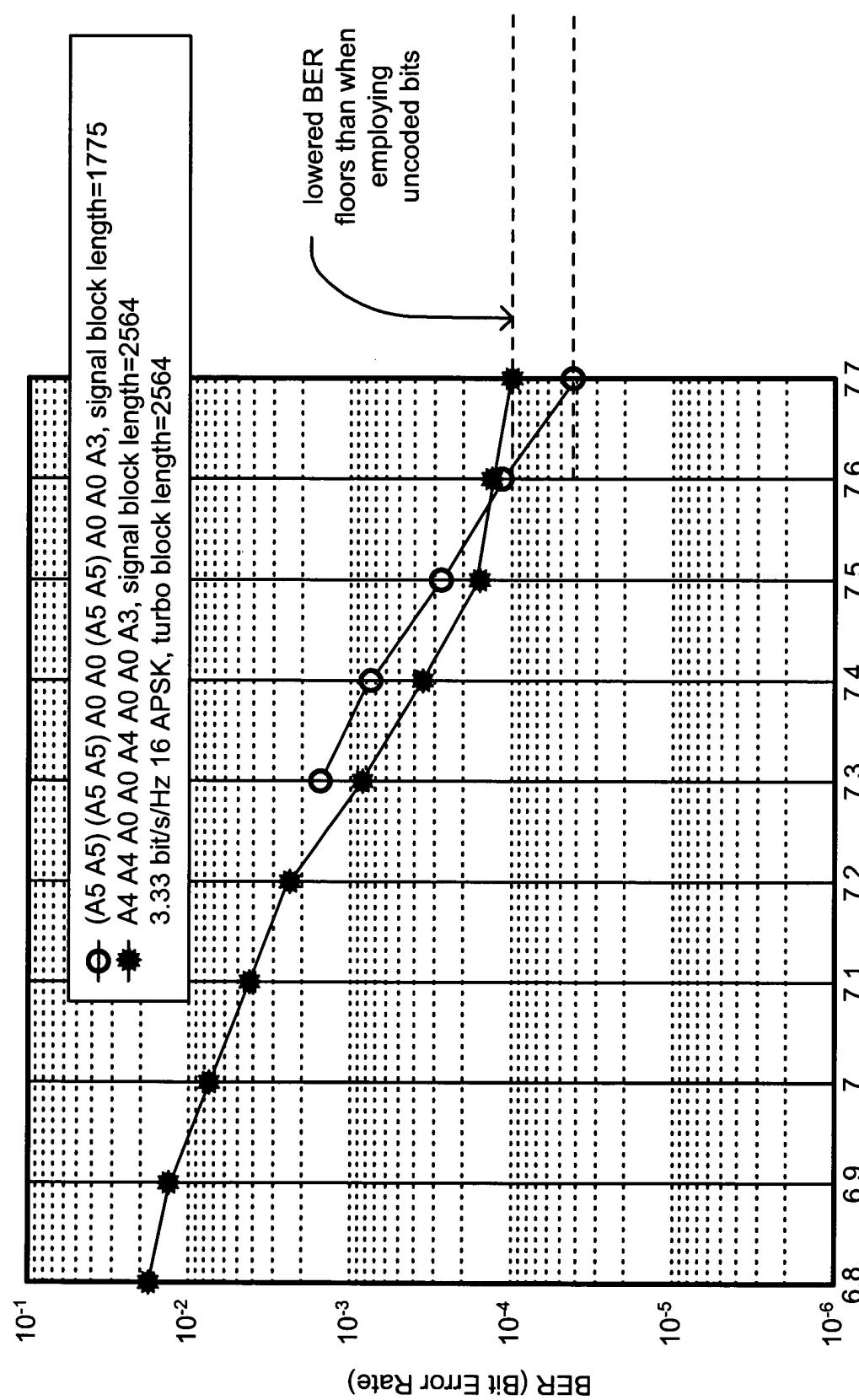
performance of 3.33 bit/s/Hz 16 APSK TTCM (shown with 4 decoding iterations)

Fig. 34

begin

encoding input bits to generate first plurality of encoded bits

selectively puncturing the first plurality of encoded bits according to a first RC (Rate Control) to produce a first encoded symbol

symbol mapping first encoded symbol according to the first RC (generating a first mapped symbol)

encoding input bits to generate first plurality of encoded bits

selectively puncturing the second plurality of encoded bits according to a first RC to produce a second encoded symbol

symbol mapping second encoded symbol according to the first RC (generating a second mapped symbol)

forming an encoded signal using the first mapped symbol and the second mapped symbol

end

TTCM (Turbo Trellis Coded Modulation) encoding method

Fig. 35

TTCM (Turbo Trellis Coded Modulation) encoding method

Fig. 36